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Review Article

Bougainvillea – A unique ornamental plant for multipurpose urban landscaping

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Abstract

Urbanization and landscaping are interrelated. Urbanization cannot be nullified due to modernization. The conception of the landscape of an urban area is also a contemporary upgrading of the innovative application of plant species. The literature on both topics is historic. An immeasurable quantity of literature and knowledge has developed on urbanization and landscaping, especially on plant species. Enormous numbers of plant species have been identified by the strenuous handwork of the scientific and landscape designer brotherhood. In recent times, Bougainvillea has come up as a remarkable specimen for urban landscaping, which has overwhelmed designers and society. An attempt has been made in the article to spotlight the heterogeneous landscape-friendly excellence of Bougainvillea. Contemplating the impressive benefaction, few scientifically based work plans have been suggested for long-term target-oriented landscaping with Bougainvillea.

Keywords: Urbanization, Landscape, Bougainvillea, Beautification, Society

Introduction

The concepts of urbanization and landscaping using plants are very old, with roots in ancient civilizations. The practice has evolved from purely beneficial purposes to complex aesthetic and ecological designs over millennia. An enormous amount of literature and knowledge has already been assembled worldwide on urbanization and landscaping. Whatever is written on these topics will be simply a repetition. The objective of the article is to discuss a different aspect that qualifies Bougainvillea as one of the most suitable plant species for urban landscaping. All landscaping-friendly qualities of Bougainvillea have been underlined. Some prominent features of urbanization and landscaping need to be illuminated before starting Bougainvillea and landscaping.

Urbanization

Urbanization happens when people shift from rural zones to the urban. People have researched and found a large number of factors that play a role in urbanization, and to mention a few are industrialization, agricultural decline, commercialization, modernization, economic prosperity, advanced infrastructure, employment scopes, sociocultural attractiveness, educational facilities, and healthcare facilities, etc. Urbanization rate differs over countries and regions, but in general, it is on the rise all over the globe, and this process is virtually unavoidable. Urbanization is complicated, and it has developed a landscape that is basically different from the natural ecosystem. The most significant environmental issues in the urban zone are air pollution.

Landscape

Landscaping is a traditional concept, but its application is a never-ending process. The literature is flooded with ideas on different aspects of landscape. Over time, there has been a remarkable rise in academic research on this sensitive social issue, and a lot of mammoth designs have been planned, researched, and written. Landscaping in urban zones is a powerful scheme to develop the green infrastructure. Landscaping is aesthetically delightful and necessary for the welfare and sustainability of progressively increasing urban areas. But regrettably, the majority of present activities appear to be mechanical in spite of noteworthy technological progress. Considering the length of the period of research on this topic, there must be a flow of knowledge and feedback from the scientific community down to the community level. The articulation of such sensitive project objectives is one of the most critical processes of project management. Success depends upon the application of correct technological applications to fulfill the project objectives and goals. The unyielding optimism and unrealistic expectations do not help to get the right product on time. In recent years, interdisciplinary scientific contributions have significantly increased technical knowledge towards the fundamental mission of urban plantation.

The objectives of landscaping have been interpreted differently by different landscapers and the summary has been illustrated in Figure 1. The main objective is to develop enjoyable environment which provide healthy breath, attractive look and a natural beauty. It has been defined in other form like landscaping helps to transform the urban region delightful and useful by reshuffling existing form and establishing pretentious benchmark, and installing plant specimen with aesthetic design. Having mentioned a number of achievements of all early efforts, it is also necessary to acknowledge a number of basic weaknesses. Author has taken the opportunity of discussing about the scientific activity of futurology in some detail as it is so relevant to current focal theme. It is now very meaningful to understand the nitty-gritty of

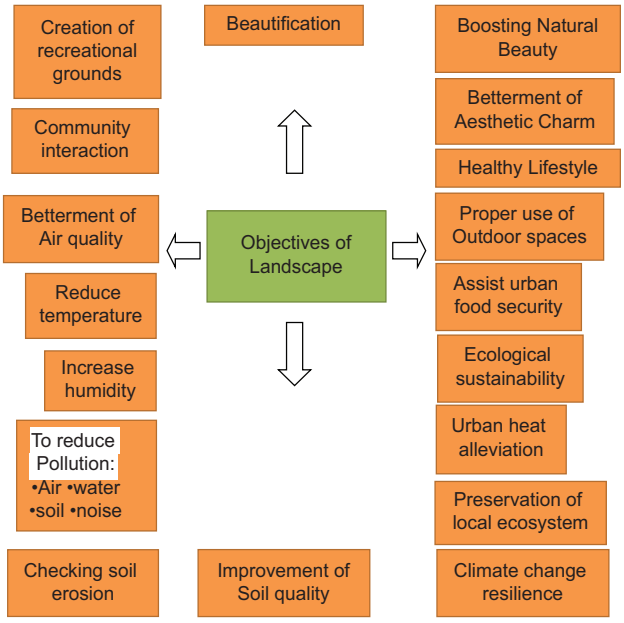

Figure 1: Summary of landscape showing different elements

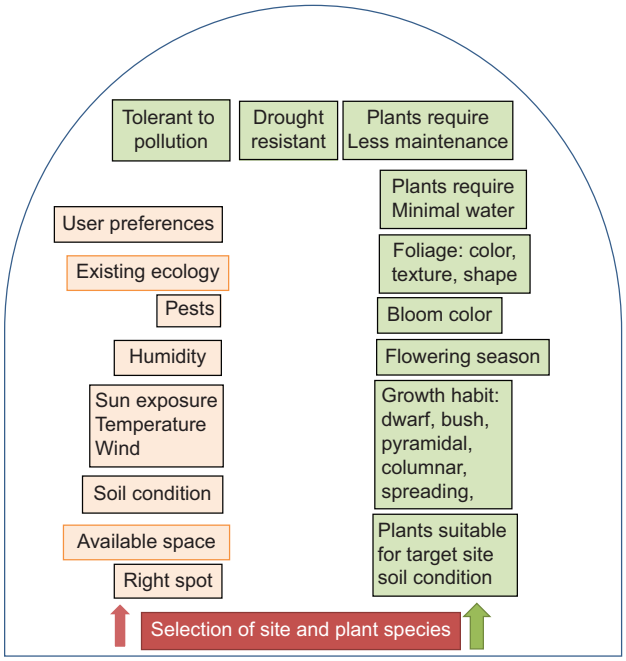

Figure 2: Showing different criteria of selection of site and plant species

project management. It is, therefore, very important to highlight some specific topic wise research results related to urban plantation.

Site selection, proper planning with meaningful foreknowledge is very important for urban plantation. Selection of right plant species has a key role to ascertain the desired goal. Few criteria which primarily are considered for selection of plant species are – suitability for target site soil condition, require less maintenance, least water demand, resistant to drought, tolerant to pollution etc. Attention is paid when selecting plant species on following aesthetic features like growth habit (dwarf, bush, pyramidal, columnar, spreading, etc.), flowering season, bloom color, color fall, foliage (color, texture, and shape), benefits to wildlife, longevity etc. (Figure 2).

A wide range of plant types have already been selected to create excellent landscape effects like trees**,** shrubs, sedges, rushes, perennials, flowering perennials, annuals, biennials, vines, ornamental grasses, ground covers, aquatic plants, cacti, and succulents, etc. It is not wise to mention the countless names of plant species and their varieties selected from each category for landscaping.

Considering the danger and risk of pollutants on environment and living system extensive research started to explore the pollutants effects on plant system. Initially screening began to identify the existing sensitive and resistance plants growing at stress environment. Early findings indicated that plants having a high degree of susceptibility are slowly depreciated and resistant plants survive the hazard (Agrawal & Agrawal, 1999). After thorough examination pollutant tolerance plants species identified were mostly heterogeneous. The list of plant species already in use for landscaping are so big, it will not be wise to mention all. Therefore, before concentrating on present target plant species (Bougainvillea) it will be judicious to mention few names of different plant species already in use in different ecological landscaping on the basis of above mentioned parameters, as reference, like - *Abies sibirica*, *Acacia nilotica*, *Acer platanoide*, *Areca palm*, *Aloe vera*, *Acacia auriculiformis*, *Acer negunda*, *Azadirachta indica*, *Alnus indica*, *Alstonia scholaris*, *Aegle marmelos*, *Artocarpus heterophyllus*, *Albezia lebbeck*, *Annona squamosal*, *Allamanda cathartica*, *Alstonia scholaris*, bamboo, *Berberis thunbergii*, *Berberis vulgaris*, *Bombax ceiba*, *Butea monosperma*, *Betula pendula*, *Bauhinia variegeta*, Bougainvillea, *Carica papaya*, *Cassia fistula*, *Cassia siamea*, *Chukrasia tabularis*, *Cornus alba*, *Cotoneaster lucidus*, *Dalbergia sissoo*, *Emblica officinalis*, *Erythrina indica*, *Eucalyptus citriodora*, *Eucalaptus terticornis*, *Ficus benjamina, Ficus benghalensis*, *Ficus indica*, *Ficus infectoria*,*Ficus carica*,*Ficus religiosa*,*Fraxinus xanthoxyloids*, Gerbera,*Gravillea robusta*, *Haplophragma adenophylum*,*Hibiscus rosa-sinensis, Jasminum sambac*, *Juniperus chinensis*, *Juniperus sabina*, *Kigelia pinnata*, *Larix sibirica*, *Madhuca indica*, *Mangifera indica*, *Manilkara zapota*, *Melia azadirachta*, *Mimusops elengi*, *Morous nigra*, *Morous alba*, *Muntingia calabura*, *Murraya koenigii*, *Neolamarckia cadamba*, *Nerium oleander*, *Peltophorum ferrugiannum*, *Philadelphus* spp., *Physocarpus opulifolius*, *Phyllanthu semblica*, *Picea obovata*, *Picea pungens*, *Pinus sibirica*, *Pinus sylvestris*, *Polyanthia longifolia*, *Pongamia glabra*, *Pongamia pinnata*, *Phyllanthusacidus*, *Plumera rubra*, *Prosopis cineraria*, *Psidium guajava*, *Prunus armeniaca*, *Punica granatum*, *Pistacia atlantica*, *Ribes aureum*, *Rosa indica*, *Rosa rugosa*, *Robinia pseudoaccacia*, *Salix alba*, *Salix ledebouriana*, *Salix purpurea*, *Shorea robusta*, *Sorbus aucuparia*, *Spiraea salicifolia*, *Syringa josikaea*, *Syzygium cuminii*, *Tabernae montana*, *Tamarix ramosissima*, *Tectona grandia*, *Tecoma stans*, *Terminalia catappa*, *Terminalia arjuna*, *Thespesia populnea*,*Thevetia peruviana*, *Trifasciata Zeylanica*,*Vitex negundo*, *Vitis vinifera*, etc.

Research report

Experimental observations have already detected various effects of pollutants on cyto-morphological, anatomical, physiological, and pollen grain features. Changes recorded were mostly changes in plant morphology, variations in stomata and epidermal cell size, increased cell thickness, chlorosis, increased trichomes and stomata, decrease in cuticle thickness, changes in stomatal opening, leaf structural changes, etc. (Yunus & Ahmad, 1980; Rao & Dubey, 1990; Gupta *et al.,* 1993; Kulshreshtha *et al.,* 1994a, b; Agrawal & Tiwari, 1997; Nighat *et al.,* 2000; Aggarwal, 2000; Patra & Sharma, 2000; Rezanejad *et al.,* 2003; Banerjee *et al.,* 2003; Shannigrahi *et al.,* 2003; Kumari *et al.,* 2005; Mandal, 2006; Verma & Singh, 2006; Shyam *et al.,* 2008; Gostin, 2009; Mutlu *et al.,* 2009; Balasooriya *et al.,* 2009; Joshi & Swami, 2009; Pawar *et al.,* 2010: Saadabi, 2011; Assadi *et al.,* 2011; Seyyednejad *et al.,* 2011; Neverova *et al.,* 2013; Giri *et al.,* 2013; Yadav *et al.,* 2013; Kumari & Prakash, 2014; Verma & Chandra, 2015; Uka *et al.,* 2017).

Muhammad *et al.* (2019) used *Bougainvillea glabra* to find out its phytomonitoring potential for vehicular pollution in the Jahan area of Saudi Arabia. They examined physiological and biochemical parameters and found a decrease in carotenoid and protein content. The species showed a greater air pollution tolerance index and resistance to stress. They recommended the species as a model plant suitable for roads for reducing particulate matter due to its high APTI and API values.

Appropriate plantation in urban areas is a struggling traditional concept, but its application is a never-ending operation, keeping pace with the continued urbanization. Bougainvillea is now one of the highest-ranking plant materials used worldwide for urban plantations.

The major pollutants in urban ambience are particulate matter, nitrogen oxides, sulfur dioxide, carbon monoxide, lead, and ozone. Research signified that pollutions influence different ways on plants. It decreases photosynthesis rate, inhibits growth and other morphological features, creates injury to leaf surface, decreases sunlight capturing capability, irregularities in stomata closure, make injury to different tissues, disturb nutrient balance etc.

Studies have validated that different anatomical traits like trichomes on the leaf surface, dense cuticles, increased frequency of stomata, unique root configuration, development of aerenchyma tissues in the root, etc., are the most distinguishing features. In addition, increased antioxidants, leaf pH, and Relative Water Content (RWC) are prominent biochemical components that help plants to combat stresses.

Voluminous research work has been done on different plant species to check out pollution effects on different morph-anatomical, cytological, physiological, and pollen grain characters. Results clearly uncovered that an evidence-based selection procedure for plant species will be more practical and the landscape will be more accurate for the future. Literature has already accumulated appreciable data on the effects of pollutants on all these parameters. Under stress situations, plants developed thick cuticle, increased number and/or altered distribution of stomata, increased number of trichomes, aerenchyma tissue, special root structure, enhanced antioxidants, leaf pH, and relative water content, pollen grain structures, etc.

Several plant species have been identified as natural resistant to air pollutants. These plants and plants growing at different pollution zone have been studied and researchers have standardized noteworthy formula which helps to determine the pollution resistance quality of the plant. They have formulated one calculative gauge Air Pollution Tolerance Index (APTI) on the basis of four criterion like leaf relative water content (RWC), ascorbic acid content (AA), total leaf chlorophyll (TCH) and pH of leaf extract. These values change significantly in plants under the influence of pollution. APTI figure serves as a beautiful guideline as bio indicators of the air pollution. It has been documented that plants having higher index value are resistant to air pollution and plants with low index value are less tolerance. It helps to select plants as bio indicators for management of air pollution. They have formulated mathematical equation that plants with APTI values less than 1 are very sensitive, 1 to 16 are sensitive, 17-29 are usually tolerant and 30 to 100 are fitfully tolerant. Plants with higher APTI values are more tolerant to air pollution than those with low APTI values. Those with low APTI values are sensitive plants and may act as bio-indicators of pollution. Selections of these resistant plants are the right choice for urban plantation, city roadside, traffic islands, and industrial belt for controlling air pollution, and sensitive plants as bio indicators (Singh & Rao, 1983; Singh *et al.,* 1991; Monk & Murray, 1995; Karthiyayine *et al.,* 2005; Tiwari & Tiwari, 2006; Tripathi & Gautam, 2007; Liu & Ding, 2008; Agbaire & Esief Arienrhe, 2009: Tripathi *et al.,* 2009; Jyothi & Jaya, 2010; Chandawat *et al.,* 2011; Mondal *et al.,* 2011; Kuddus *et al.,* 2011; Govindaraju *et al.,* 2012; Krishnaveni *et al.,* 2012; Thambavani & Maheswari, 2012; Babu *et al.,* 2013; Kumar & Nandini, 2013; Kapoor, 2014; Tsega & Prasad, 2014; Rai *et al.,* 2014; Nayak *et al.,* 2015). Appreciable amount of work has been carried out on different plant species. Few names are mentioned as reference like *Eucalyptus globulus* Labill., *Ricinus communis* L., *Cassia viz., C. siamia* L. and *C. fistula* L., *Chenopodium album* L., *Chenopodium botrys* L., *Lilium martagon*, *Pinus sylvestris* L., *Ficus Benghalensis* L., species of gymnosperms, *Eucalyptus camaldulensis* Dehnh. Bougainvillea, *Psidium guajava* L., *Catharanthus roseus*, *Zinnia elegans*, *Nicotiana plumbaginifolia* L., *Picea rubens* Sarg., *Pinus taeda* L., *Pinus sylvestris* L., etc.

It is universally acknowledged that the proper selection of plant species is one of the most efficient bio-remediation procedures to control pollution.

Research has established following distinctive features in different species exposed to air pollutions. It has been observed that thick stem, fleshy and thick leaves and flexible petiole make plants pollution tolerant. Cytological

disturbances have been recorded due to pollution (Ivanescu & Gostin, 2007). Chehregani *et al.* (2004a) examined chromosome of *Zinnia elegans* L. growing in both polluted and non-polluted region. They observed different abnormalities in meiosis chromosome segregation like clumping and stickiness in chromosomes in metaphase, failure of chromosomes in entering metaphase arrangement, presence of 1-6 laggards in anaphase I and II and telophase disturbed cell division, etc. They observed that the number of cells increased with laggard chromosomes in polluted plants significantly. Gritsan (1993) observed increased frequency of chromosomal abnormalities in both root tip and shoot tip mitosis in wheat and barley growing fluoride polluted region. Mutation frequency was more in the meristematic cells of plants (Holmberg & Ahlborg, 1983; Mauderly *et al.,* 1986).

Pollution stress can induce perturbations in different features of plants, including pollen structure. A good amount of work has already been conducted on the effects of pollutants on pollen grains and has found significant changes in morphological, biological, and chemical characters. Experimental results indicated that pollen grain characters can be changed through mutations and many other natural and manmade operations. Male gametes are shielded by pollen exine from natural stresses. Studies on pollen grain structural features of pollution-tolerant plants signify the role of pollen structure against hazardous situations. Studied conducted on plants growing at both normal and polluted areas and the studies were carried out using both LM and SEM, and following changes were observed – disturbance in pollen germination and viability, shrinkage in pollen grain size, disturbed pollen development, breakage in exine, thinning and fragility of exine, presence of particulate matter on the surface, pollen deformation, changes in exine reticulation pattern etc. (Sidhu, 1983; Ruffin *et al.,* 1983; Holmberg & Ahlborg, 1983; Mauderly *et al.,* 1986; Wolters & Martens, 1987; Nilsson & Berggren, 1991; Majd & Mohamadi,1992; Cerceau-Larrival *et al.,* 1996; Peltre *et al.,* 1999; Lhuissier *et al.,* 1999; Iannotti *et al.,* 2000; Rezanejad *et al.,* 2003; Koti *et al.,* 2005; Okuyama *et al.,* 2007; Azzazi & Zahran, 2008; Kalbande *et al.,* 2008; Rezanejad, 2009; Yousefi *et al.,* 2011; Amjad & Shafighi, 2012; Surekha & Jaiswal, 2014; Azzazy, 2016; Sénéchal *et al.,* 2015; Hélène Sénéchal *et al.,* 2015; Gunjekar & Kalkar, 2018). Such studies have been conducted on *Cassia siamia* L., *Cassia fistula* L., *Ricinus communis* L., Eucalyptus, Ruellia, tuberose, etc. A few experimental results are elaborated as a reference. Azzazy (2016) examined pollen morphology of *Eucalyptus globulus* Labill. growing in both a normal environment and the industrial pollution zone. Results indicated pollen grains of plants growing in the control area were normal in size, shape, and sculpture. Pollution-affected pollen grains showed shrinkage in size, thinning of exine, protrusion elements on the pollen surface, and particulate materials attached to the pollen surface. Gunjekar and Kalkar (2018) observed pollen size shrinkage, breakage of exine, and presence of particulate matter in the pollen size of pollution-exposed *Ricinus communis* L. Surekha and Jaiswal (2014) examined pollen morphology of *Cassia siamia* L. and *C. fistula* L growing at both normal and polluted regions. They have reported the exine ornamentation pattern of both materials in the normal region. Pollen grains of both materials from the polluted area showed shrinkage in size, exine breakage, and accumulation of particulate matter on the pollen surface. A few bougainvillea varieties developed integrated pollen structural resistance through environmental variations and can survive quite well under polluted situations. Pollen exine is composed of sporopollenin, which protects male gametes from all external stresses. Pollen grains are exposed to the outer environment when they are transmitted to the stigma by different biotic and abiotic agents (Datta, 2005). Datta (2005) examined the surface pattern of pollen exine in 24 heterogeneous common pollution-tolerant tropical plants, including trees, shrubs, and herbs. The majority of the pollution-tolerant plants have tectate exine (outermost layer of pollen grain, which forms a continuous covering over pollen made of sporopollenin) where the surface is either wholly covered or barely perforated. Few species have semitectate exine (tectum is discontinuous, covers less than 50% of pollen surface, developing in a net-like or reticulate pattern with gaps) with a greater portion of perforated area. Bougainvillea showed true reticulate exine, forming a network-like arrangement where the width of the perforation was greater than the width of the surrounding exinous muri. There were the perforated areas or lumina occupied by some solid projections (second set of columella) so that the open exposed surface area was virtually reduced. In the present study, a good number of varieties conform to similar pollen micromorphology characteristics, supporting the pollutant-tolerant nature of bougainvillea. Pollen morphology of a large number of varieties has been studied (Datta & Datta, 2024a; Tripathi *et al.,* 2017). One can follow the technical details of pollen preparations, pollen description terminology, and pollen morphological characters of 84 Bougainvillea varieties from Datta and Datta (2024b).

Pollen grain characters of *Zinnia elegans* Facq growing in both polluted and non-polluted zone were studied and observed various abnormalities like decrease in fertility, folded pollen grains, disrupted tectum, deposition of particles on pollen grain surface etc. in polluted area (Chehregani *et al.,* 2004b).

Studies verified that the allergenicity of pollen grains is increased due to pollution (Cerceau-Larrival *et al.,* 1991; Behrendt *et al.,* 1992; Jilek *et al.,* 1993; Helander *et al.,* 1997; Emberlin, 1998; Chehregani *et al.,* 2004a, b; Chehregani & Kouhkan, 2008; Radauer *et al.,* 2008). However, the effect of atmospheric pollution on the dispersion and allergenicity of these subparticles is, for the moment, still not clearly and fully elucidated. More studies are required in order to better understand the mechanisms of pollutant rupture.

Bougainvillea

Considering the topic of the article, some prominent features of Bougainvillea need to be illuminated.

Bougainvillea is attached to the family Nyctaginaceae and in the tribe Mirabileae. It is a unique genus in the monotypic subtribe Bougainvilleineae (Gills, 1976; Hammad, 2009). It originated in tropical and sub-tropical South America and is now widely grown in most tropical and sub-tropical countries. Commerson collected it from Rio de Janeiro, Brazil (Ninan *et al.,* 1959; Bor & Raizada, 1954). Successively different authors enriched the literature covering diverse perspectives like history, scattering, classification, cultivation, uses, horticultural importance, flowering attitude, breeding, development of new varieties, varietal descriptions, etc. (Datta *et al.,* 2017, 2022).

Bougainvillea is now a very important ornamental species in floriculture for its manifold characteristics and multipurpose use, especially for landscaping. It is now a very sensitive plant in terms of the economic budget due to its demand for landscaping. There are innumerable varieties that are influential from a floriculture point of view. Bougainvillea is a remarkable addition to any garden.

Unique changes in growth habit have been noticed in Bougainvillea in the course of domestication through human selection pressure, complicated interspecific crosses among elemental species and varieties, and spontaneous mutation.

Much has been worked out and written on Bougainvillea regarding its diversity and use. Bougainvillea is separated into Single Bracted and Double or Multi bracted groups. Most of Bougainvillea is in the single bracted group with wide spectrum of bract color, shape and size. Bract color plays a symbolic role in recognizing/adorning different cultivars and makes Bougainvillea a wonderful garden plant. All single bracted Bougainvilleas have been classified into eight color groups on the basis of color variance viz. Red-Purple Group, Purple-Violet Group, Purple Group, Red Group, Violet Group, Orange and Orange-Red Group, White Group, Bi-colored Group. In some varieties there was change in color shade of bract with age. In some cases the color was mixed. Out of eight multi-bracted group, color of matured bracts of 'Cherry Blossom', 'Mahara' and 'Mahara Variegata' were Red-Purple Group, 'Los Banos Beauty' was Purple Group and 'Los Banos Variegata' was Purple-Violet Group, 'Archana', 'Pallavi' and 'Roseville's Delight' were bi-coloured. Some bougainvillea varieties change their bract color with age. It flowers lavishly almost all the year round and already occupied pride position in floriculture and landscaping. It has earned the highest level of significance and broadly recognized all-purpose ornamental plant. In addition to growth habit, wide range of variability in bract colors and chlorophyll variegations in leaves made Bougainvillea unique. Additionally, it grows in different climatological zones and soil types. Bougainvillea has been identified having unique characteristics like drought, saline, and pollution tolerant. Current Bougainvillea depict the cumulative diversity in different prominent features like - growth habit (upright, semi-upright, spreading, drooping, climbing); internode length (short, medium, long), young shoots (glabrous, tomentose, densely villous), thorn (long, slender, short slender), bract arrangement, bract color; bract size; bract apex, bract base, flower size; leaf color; leaf size; shape of the leaf apex; leaf lamina, petiole length, number of branches per unit area; number of thorns per unit area; thorn size; stem color etc. (Datta, 2021, 2024). All diversity in Bougainvillea developed through indiscriminate hybridization, somatic mutations, natural and intentional breeding, geographical movement of elemental species, adaptation, human selection pressure, chromosomal manipulations, induced mutation, etc. Bougainvillea is possibly one ornamental plant where unusual modifications have taken place in almost all characters during domestication through selection pressure and through complex inter-specific crosses among elemental species and varieties and spontaneous mutation. Human intervention, through practices like desired breeding and cultivation, has been the primary driver in developing the Bougainvillea plant to be useful for a wide variety of purposes (Figure 3). It has already acquired diversity in all mandatory multipurpose characteristics like variation in habit, growth and color pattern of different cultivars. Culturally it can be grown as shrub, bush, climbers, specimen plant, hedges, topiaries, ground covers, standards, on pergolas and trees, arches, pot culture, flowering hedge, cut flowers, slopes and mound, bonsai, hanging basket, cascade, bonsai etc. It has earned drought, saline and pollution tolerant traits which certify it for plantation in the industrial regions and in the areas where other ornamental flowering plants do not easily thrive well. Suitable genotypes for each category have been selected. Above all, diverse color complexion of bracts increases emotional advantages. Every landscape design at urban zone and roads, parks, gardens with Bougainvillea will be more vibrant with these characteristics. Bougainvillea with its sparkling bracts and variegated leaves and due to its artistic artificial designs is now recognized as a universal image. Bougainvillea is a dazzling focus of attention in any garden. Its display in any form composes a wonderful display.

Bougainvillea can be easily framed into numerous landscaping designs. The grafting technique has now been systematized excellently in Bougainvillea. This has

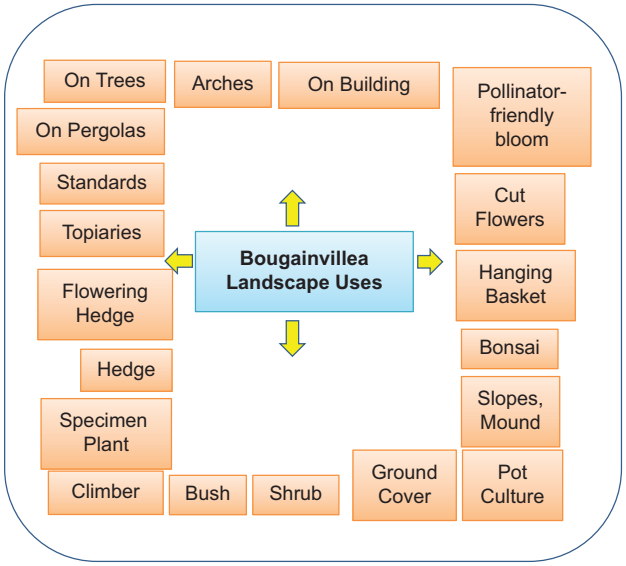

Figure 3: Different manifestation of Bougainvillea landscaping

opened a remarkable pathway to mold and create desirable, multicolored, dazzling specimens. Grafting technique has elevated Bougainvillea to a very respectable position in the market, and it has enriched the economic status of the growers. Such a design has already been very popular in the landscaping world (Figure 4).

Extensive trial and keen observations have identified Bougainvillea as a multipurpose plant due to the variation in habit, growth and color pattern of different cultivars and are grown as pot plants, standard, hedges, bush, climber, bonsai, and landscape, as an espalier, factory gardens, institutional gardens, municipal gardens, terrace garden, wind curtain, topiary, pergola and various other multipurpose. It is a multipurpose plant that can be molded as a vine, shrub, or tree, making it suitable for various applications in gardens, parks, and landscapes. It can be grown in containers, hanging baskets, or directly in the ground, and it is often used for climbing walls, trellises, or fences (Figure 3). Concentrated efforts of scientists and breeders have already detected a series of varieties suitable for various purposes, including pollution-tolerant varieties, from their performance (Pal & Swarup, 1974; Raza *et al.,* 1988; Salgare & Nath,1991; Pal *et al.,* 1999; Sharma, 1996; Sindhu, 2001; Kumar *et al.,* 2007; Singh *et al.,* 2015; Sharma *et al.,* 2015; Sindhu & Swaroop, 2015).

Climber

Chitra, Dr.R.R. Pal, Lady Mary Barig, Mary Palmer, Partha, Subhra, Mrs. H.C. Buck, Lilac Queen, Hawaiin White, Jubilee, President, Sensaton, Parthasarathy, Surekha, Spring Festival, Scarlet Gory, Blondie, Enid Lancaster, Lateritia, Lilac Perfectio, Shubhra, Thimma, Glabra,Cherry Blossom,Splendens, Asia, Elizabeth, Pink Beauty, Gopal, Formosa, Spring Festival, Glory, Purple Star, Louise Wathen, Dr. R.R. Pal, Meera, Mahara, Partha, Mary Palmer, Ranee, Shubhra, Roseville's Delight,Los Banos Beauty, Golden Glory, Scarlet Queen, Shweta, Walker, Yellow Queen, Singapore Dark Red, Cherry Blossom etc.

Specimen plant

Dr.R.R. Pal, Blondie, Begum Ali Yuwar Jung, Mary Palmer, Sonnet, Mahara, etc.

Group planting

Tomato Red, Chitra Cherry Blossom, Begu Sikander, Mary Palmer, Arjuna, Gopal, Flame, Mahara Variegata, Padma, Purple Star, etc.

Shrub/Bush

Asia, Flame, Sonnet, Spring Festival, Summer Time, Tomato Red, Dr.R.R. Pal, Versicolour, Parthasarathy, Dr. H.B. Singh, Glabra, Mahara, Roseville's delight, Zakiina, Mary Palmer, Thimmaq, Shubhra, Blondie, etc.

Topiary

Parthasarathy, New Red, Lady Richard, Happiness, Hawaiian, Perfection, Purple Star, Formosa, Cherry Blossom, Begum Ali Yawar Jang, Palekar, Dog Star, Isabel Green Smith

Hedge

Dr. R.R. Pal, Campbell, Mary Palmer Special, Mrs. H.C. Buck, Partha, Sanderiana, Shubhra, Thimma, Killie Campbell, Partha, Parthasarathy, etc. For dwarf hedges, suitable cultivars are Glabra Sanderina, Dr. Harbhajan Singh, Joe, etc.

Bush

Mary Palmer, Thimma, Chitra, Mahara, Shubhra, Roseville's Delight, Chandrabieri, Jayalakshmi, Golden Glow, Blondie, Dr. R.R. Pal, etc.

Figure 4: a-c) showing grafting, and d-f) showing multivariate grafted specimen

Standard

Begum Sikander, Asia, Easter Parade, Formosa, Glabra, Gokul, Hawaiian Beauty, Jayalakshmi, Lady Mary, Baring, Mary Palmer, Mrs. H. C. Buck, Isabel Greensmith, Louise Wathen, Mahatma Gandhi, Orange King, Palekar, Los Banos Variegata, Rose Queen, Shubhra, Thimma, Trinidad, Sensation, Lord Willingdon, Spring Festival, Speciosa etc.

Pot Plant

Begum Sikander, Blondie, Cherry Blossom, Chitra, Flame, Krumbeigal, Mahara, Mrs H.C. Buck, Mary Palmer, May Palmer Special, Summer Time, Stanza, Tomato Red, Vishakha, Wazid Ali Shah, Shubhra, Jaya Lakshmi, Formosa, Lady Richard, Happiness, Zakirina. White blooms (Miss Alice), orange blooms (Bambino Baby Sophia), pink blooms (Rosenka, Singapore Pink), red blooms (La Jolla, Crimson Jewel),magenta-red blooms (Oo-La-La, Raspberry Ice), purple (Vera Deep Purple) are good choices.

Arches and pergolas

Golden Glory, Cherry Blossom, Mahara, Partha, Mary Palmer, Roseville's Delight, Los Banos Beauty, Scarlet Queen, Jennifer, Fermie, Shweta, Shubhra, Yellow Queen, Singapore, etc.

As an espalier

Lady Mary Baring, Partha, Shubhra, Dr. R.R. Pal, Mary Palmer, Thimma, etc.

Ground cover

Dr. H. B. Singh, Dr. R.R. Pal, Mrs. H.C. Buck, Shubhra, Splendens, etc.

Bonsai

DR. Harbhajan Singh, President, Isabel Greensmith, Tomato Red, Thmma, Golden Glow, Pink Pixie, Louis Wathen, Orange King,Magnifica, Mary Palmer Special, Glabra Sanderiana, Snow White, Zakiriana, Mrs. H.C. Buck, Shubhra, Begum Sikander, etc.

Hanging baskets

Scarlet Queen Variegated, Glabra Variegated, Dr. Harbhajan Singh, Isabel Greensmith, Palekar, Blondie, Dr.R.R. Pal, Mrs. H.C. Buck, Jawahar Lal Nehru, Shubhra, Marry Palmer, Tomato Red, etc.

Cascade

Begum Ali Yawar Jung, Palekar, Isabel Green smith, Dogstar, etc.

Pollution resistant

Blondie, Dr. H.B. Singh, Dr. R.R. Pal, Chitra, Paleker, Mrs. H.C. Buck, Mary Palmer, Shubhra, Partha, Zulu Queen, etc.

Discussion

For preparation of this article enormous volume of accessible literature was utilized and sensibly assessed.

It is now needful to sensitize ourselves about our past research results, which have enriched our knowledge and literature, and carefully analyze their impact on the Bougainvillea industry. Landscaping with Bougainvillea is a long-term project, and one must realize the limitations and technically feasible measures before starting the plantation. Because landscaping with only Bougainvillea is a very sensitive project. It is paramount to reorganize the scientific and technological precedencies before starting landscaping with Bougainvillea. Reviewing the remarkable technological expertise created until now, a future work plan has been put forward, which will help in selecting and developing environmentally friendly varieties for better landscaping.

Chromosomes act as a sensitive biological marker to determine the genotoxic influence of pollutants. Routine examination of chromosome structural changes in the form of aberrations like fragmentation, bridges, laggards, micronuclei, exclusion, etc., may be performed on Bougainvillea under both normal and stress conditions. This information will help to identify varieties sensitive and/or tolerant to pollutants.

For upcoming breeding on Bougainvillea, there is a necessity to shift our mindset from a random breeding strategy towards directive breeding for creating specific desired traits by selecting promising parents. Selective breeding is now very important to develop desirable strains. The development of dwarf varieties will be a good option. Increased temperature, varying rainfall, enhanced carbon dioxide, etc., are influencing agricultural products. Bougainvillea is already unique for its drought, saline, and pollution resistance characteristics. Research may be expanded to create further favorable strains resistant to such abiotic stress through selective breeding.

Existing appropriate varieties have been selected on the basis of their long term performances. These varieties have mostly originated through various operations like bud sports, open-pollinated seedling selection, indiscriminate intervarietal hybridization, chromosomal manipulations, induced mutations, and selections. Most literature highlights three basal/elemental species i.e. *B. glabra Choisy, B. spectabilis* Wild*, and B. peruviana* Humb etBonql which have contributed maximum in origin of present day novel varieties. Literature accounts for some more basal species which may not participate in breeding but enriched with

beneficial characters. The author collected names of few such species from The Plant List as follows- *Bougainvillea spinosa* (Cav.) Heimerl: (simple leaves, broad, splashy flower, vibrant pink-purple bracts); *Bougainvillea campanulata* Heimerl: (perennial vine, suitable under full sun to partial sun, prominent flowers, dazzling bracts colors); *Bougainvillea stipitata* Griseb.: (flowers greenish and persist five days, nectar present, self-incompatible, pollinators very important for pollination); Bougainvillea pomacea Choisy: (perennial vine, grows under full sun to partial shade, flowers attractive, vibrant showy bract color); *Bougainvillea lehmanniana* Heimerl; *Bougainvillea berberidifolia* Heimerl; *Bougainvillea herzogiana* Heimerl; *Bougainvillea infesta* Griseb.; *Bougainvilleatrollii* Heimerl; *Bougainvilleamodesta* Heimerl; *Bougainvilleapachyphylla* Heimerl ex Standl.; *Bougainvillea malmeana* Heimerl.; *Bougainvillea praecox* Griseb.: (deciduous spiny shrub or tree, suitable as a tree landscaping, prefers sunny location, frequently found on calcareous, clayey soils, tolerant to dry soils, seed germinationvirtually 100%); *Bougainvillea Arborea*: (tropical, salt tolerant, tree, thorn less, fragment, bracts lavender-pink, year round blooming). Survey report indicate that some species are suitable for breeding; some as cut flower (*B. pomacea*, *B.campanulata*); fragrant (*B. stipitata*, *B. Arborea*); fruit/seed production (*B. stipitata*); some suitable for ornamental and landscaping (*B. praecox*); 100% seed germination (*B. praecox*); some thornless, salt-tolerant (*B. Arborea*).It is very remarkable that no breeding related papers including these elemental species are available. But some species have been reported to have desirable features. Breeders may initiate new approach with present knowledge to incorporate these species in breeding programme and assess for their quality to be used directly in landscaping (Datta, 2022, 2024).

It is the right time to select and develop the most appropriate genotypes for large-scale development to meet the increasing demand for Bougainvillea for landscaping. Science-based technical results and improved and newly developed varieties through directive breeding will position Bougainvillea in the global landscape industry.

Determination of susceptibility and resistance level of different species and varieties on the basis of different index like morphological (vegetative and floral features), anatomical features, chromosome marker, pollen grain characteristics and biochemical measures will be very important to shine Bougainvillea in landscaping.

Reports claim that certain category of flowers are effective in griping injurious pollutants and reduces atmospheric pollution level. More research is necessary in this field. Bougainvillea is now most prominent in landscaping with its versatile bract colors and size. Work may be initiated to find out the visible and invisible pollution absorbing capacity of bracts color wise for designing future landscape with Bougainvillea.

Pollen grain characters are genetically fixed. These features are sensitive to environmental stresses and mutagen treatments and mutable. Genetic control and changes in pollen aperture and exine surface sculptures due to mutations have been thoroughly reviewed recently (Datta & Datta, 2024a). Pollen grain characters (pollen shape, size, germination, exine ornamentation, allergenic properties, etc.) should be studied in already resistant varieties and compared with other varieties for selection of new and correct varieties. It is necessary to strengthen research on Bougainvillea to identify varieties suitable for mitigating air pollution. Pollen morphological and structural diversity has been reported earlier by many researchers in solving interrelationships in different plant species. Recent studies clearly indicated that pollen architectural features serve as a parameter of pollution-tolerant plants under stress conditions. Pollen ornamentation pattern needs little stretching to enrich this data for Bougainvillea landscaping. Tectate or semitectate exines are the pollen features in the majority of angiosperm plants. Praglowski and Punt (1973) reported that the tectate (outermost layer of pollen grain made up of sporopollenin) grains have an uninterrupted or little (20%) perforated tectum, and in semitectate grains, the perforated area is more (80%) of the total surface of the exine. Datta (2005) from her exploration mentioned that most of the pollution-tolerant plants had tectate exine. Few tolerant plants had reticulate exine with bigger perforations, but the presence of columella within lumina reduced the exposed surface. Such mystical likenesses in exine ultrastructure in the plants are presumed to be pollution-resistant.

Bougainvilleas, with their long evolutionary history, have experienced different environmental stresses and developed modifications in both vegetative and reproductive characters (Datta 2021). Such alterations might have enabled Bougainvillea to develop tolerance against pollution (Datta & Datta, 2024b).

Bougainvillea pollen grains are quite low allergenic. Additionally, the amount of pollen production is low; pollens are heavy and sticky, mostly insect-pollinated (not wind-pollinated); it has not been registered in the allergen database with its specific allergens. However, allergic reactions (asthma, rhinitis) have been reported in susceptible individuals. In summary, due to its low pollen production and insect-pollinated nature, Bougainvillea poses minimal risk for pollen-related allergies for most people. More scientific research is appropriate for a better realization of pollutant effects on the allergenic property of Bougainvillea.

Bougainvillea has developed many landscape-friendly characteristics like plant growth features, bract diversity, flowering, drought, and saline resistance, etc. through genetic diversity. Researchers have already identified several varieties suitable for a specific purpose on the basis of their performance. Now, research is needed to check the truth of the scientific background of these features.

Bougainvillea has already occupied a very respectable position in landscaping among ornamentals. It is very ideal for landscaping of industrial region as well as for road dividers for pollution tolerant character. Figures 3 to 6 portray the comprehensive diversity of Bougainvillea and its fitness for excellent representative plant species

for desired landscaping. The choice of individual Bougainvillea species for landscaping is very broad due to its enormous diversity in bract color and chlorophyll variegations (Figures 5 and 6). Figure 6 shows how beautifully and majestically Bougainvillea has been utilized in landscaping. Two broad types of display specimens can be developed- one on the basis of bract color and another on the basis of variegated leaves. Individual specimen/standard may be prepared on the basis of single bract color (Figure 6n) and double bract color (Figure 6o) varieties. Area may be covered with selected variegated varieties (Figure 6a), area may be covered with mixed color varieties (Figure 6b) and area may be covered with one colored varieties as per choice. Further, Bougainvillea may be presented in two forms in landscape. Colorful lay out with colorful bract varieties as primary choice (Figure 6c-f) and green vegetative display (Figure 6a,i,j,k) as secondary choice. Budding/grafting technique has opened a new direction to develop distinct two, three, four, and multicolor varieties specimen (Figures 4a-f). These specimens can also be molded to any attractive architectural form (Figure 6k,l,m,p,q). Figures 6 b-m,p and q are the few representative of Nanning Botanical garden (Qingxiushan), China.

As the Bougainvillea occupied a very decorous placement in urban landscaping on the basis of existing experience, a number of basic scientific information will further enrich it for perpetual utilization. The author takes the chance to justify the need for the incorporation of already explored scientific knowledge in Bougainvillea landscaping. The author made a thoughtful effort to develop an absolute landscape tool kit for Bougainvillea on the basis of its present diversity, technical ingenuity, success benchmark, and scientific background. The article would evoke a creative response among all related to Bougainvillea breeding and landscaping, and will help landscapers to develop futuristic science-based long-term projects. Worldwide utilization and demand have already formed a separate industry- the Bougainvillea Industry.

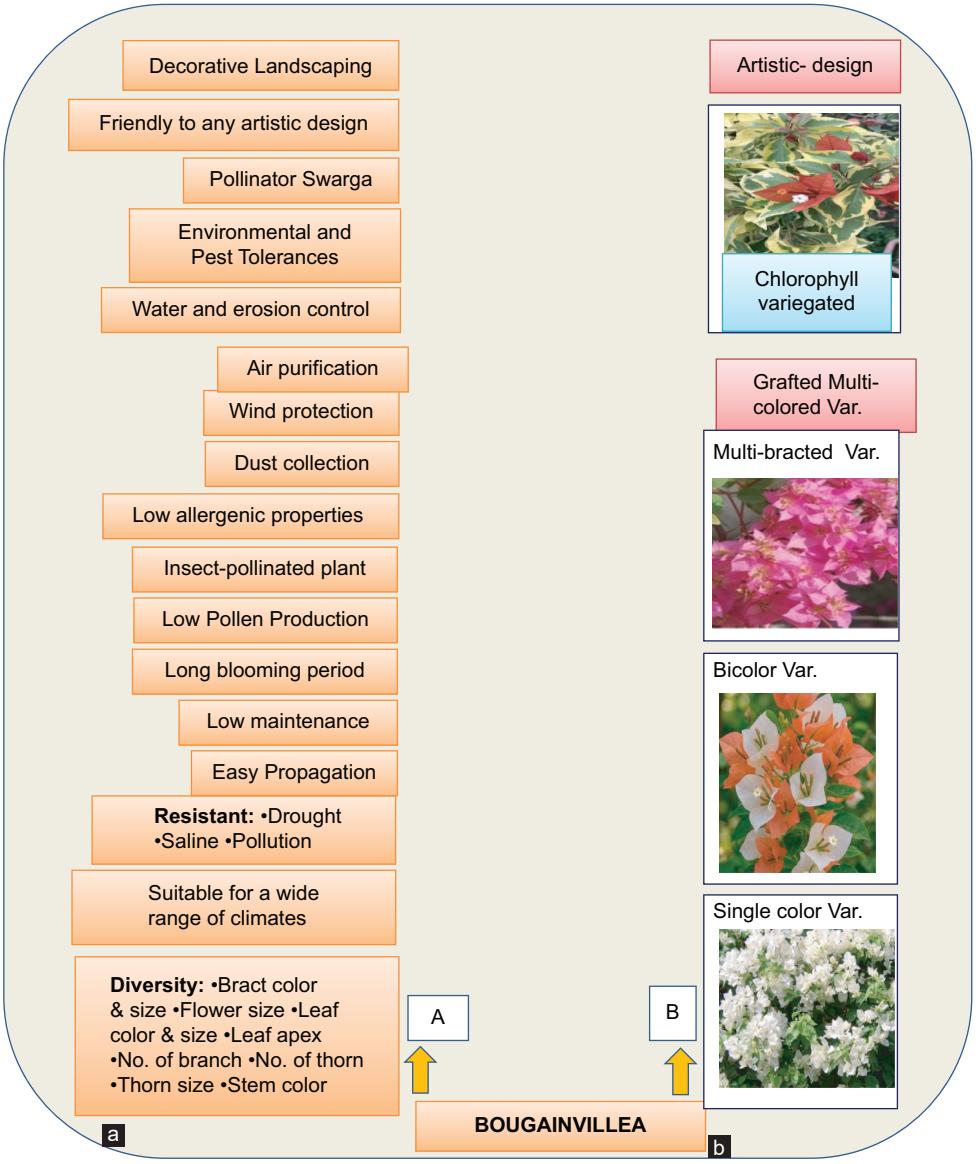

Figure 5: a) Different merits of Bougainvillea for landscaping and b) different layout plan of landscaping with Bougainvillea

Figure 6: Representative style of layout. Group representation of a) variegated varieties and b) bract color varieties. b-f, m, p, q) Artistic style of presentation of bracted varieties, i-l) Artistic design of foliage dominant variety, g, h) Topography of landscape design with Bougainvillea. b-m, p, q) Different symbolic specimen of Bougainvillea are from garden in Nanning Botanical garden (Qingxiushan), China. Pictures provided by S. Z. Hualao

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